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The Proximity Effect in Ultrathin Granular Pb Films*

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We present electron transport measurements that demonstrate that Pb films that are on the insulating side of the two dimensional superconductor to insulator transition can be made superconducting by depositing a normal metal, Ag, on them.

1. INTRODUCTION

Putting a normal metal in intimate contact with a superconductor degrades some of the superconductor's properties and, under certain circumstances, enhances others. The proximity of the normal metal weakens the pairing potential and reduces the mean field transition temperature, T_c, of the superconductor[1]. On the other hand, if the superconductor has a granular morphology, then placing a normal metal among its grains can enhance the intergrain coupling strength and thereby increase the intergrain critical currents. We have investigated the effects of depositing a normal metal, Ag, onto ultrathin Pb films that are on the insulating side of the superconductor to insulator transition. The effects of the normal metal are dramatic. The insulating Pb films can be driven through the superconductor to insulator transition by the addition of Ag.

2. SAMPLES

The films used in these studies were evaporated onto fire polished glass substrates held at 8 K in a cryostat immersed in liquid Helium. The cryopumping action of the walls of the cryostat insures that the evaporated films are free of contaminants. Measurements of the sheet resistance as a function of temperature, $R(T)$, were performed *in situ*[2]. In what follows, we express the mass deposited in terms of the thickness of a layer of bulk material of the same areal density. For $R_N \equiv R(8K) > 300\Omega$, both D_{Pb} and D_{Ag}, the thicknesses of the Pb and Ag layers, are smaller than the superconducting coherence length.[2]

3. RESULTS AND DISCUSSION

In Fig. 1a, we show logarithm of R as a function of T for a Pb film of 40 Å topped with increasing amounts of Ag. R_N of Pb films thinner than 60 Å are too large to measure. The evolution of $R(T)$ with increasing Ag thickness is qualitatively very similar to what is observed in pure granular films.[3,4] The deposition of $\approx$ 25 Å of Ag produces the uppermost curve of Fig. 1a which rises nearly exponentially with decreasing temperature. This film was probably an insulator at $T = 0$. Subsequent evaporations of small amounts of Ag, $\approx$ 1Å, transform the film's insulating behavior into superconducting be-

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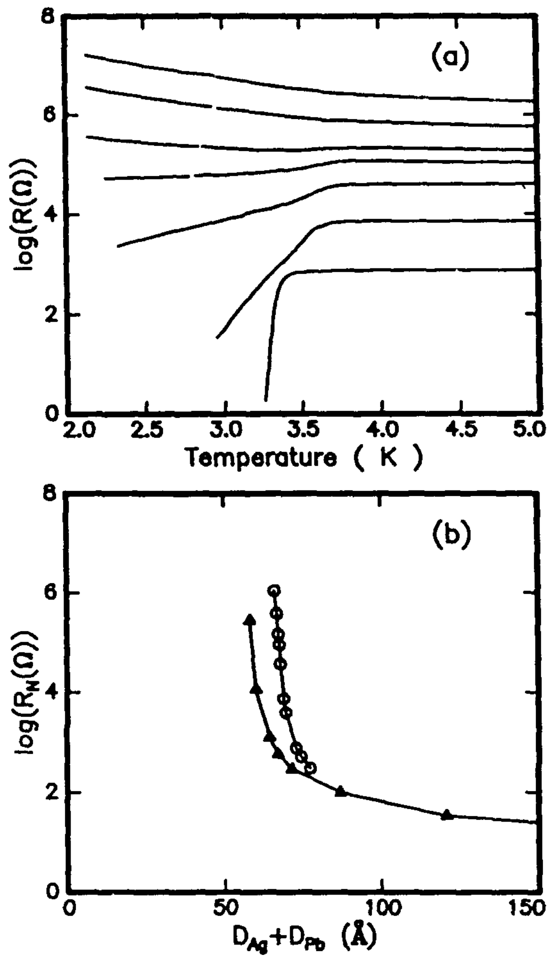

Figure 1. a)$R(T)$ for a $D_{Pb} = 40$Å film topped with different amounts of Ag. b) Film thickness dependence of R_N for a pure Pb film and the films in a).

havior. The transition temperature of $\approx 3.6K$ is significantly less than the bulk Pb value of 7.2 K. Thus, these data show an insulator to superconductor transition that occurs as the amount of *normal metal* in the sample is increased.

We can learn about the morphology of this Pb/Ag system by examining the film thickness dependence of R_N. In Fig. 1b we plot the logarithm of R_N vs. $D_{Pb} + D_{Ag}$ for pure Pb films (closed symbols) and Pb/Ag films with $D_{Pb} = 40$Å (open symbols). For the smallest thicknesses, R_N decreases nearly exponentially with thickness indicating that electron tunneling processes dominate the transport and therefore, these films have a granular morphology near the insulator to superconductor transition[3]. R_N would drop more slowly than exponentially if the films had a uniform morphology. Thus, the data imply that the Ag coats the Pb grains enlarging them and reducing the intergrain separation. This enhances the intergrain Josephson couplings which reduces the fluctuations in the phase of the superconducting order parameter and leads to zero resistance. The Cooper theory of the proximity effect should work for this picture since it assumes that the normal and superconductor regions are in intimate contact and have dimensions smaller than a coherence length. The grain T_c's should be reduced by a factor of $exp(-D_{Ag}/D_{Pb}) \approx 0.5$[1] in good agreement with the data.

4. SUMMARY

We have used Ag, a normal metal, to transform an insulating granular Pb film into a superconductor. The deposited Ag acted to increase the intergrain Josephson coupling energies and thereby enable the superconducting order parameter to develop phase coherence over the entire sample.

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